PREY PREFERENCE FOR ASIAN CARP AND SOFT PLASTIC LURE INGESTION BY LARGEMOUTH BASS

BY

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THESIS

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Abstract

Invasive bighead (*Hypophthalmichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix*) have become established throughout much of the Mississippi River basin. In many areas, these two species comprise a significant proportion of the fish biomass. Despite their prevalence and potential for negative environmental impacts, to date, there has been no assessment of vulnerability to predation of Asian carp compared to native species. We sought to examine largemouth bass (*Micropterus salmoides*) predation on juvenile bighead and silver carp in relation to common native prey species. Prey species selection experiments in 2-m pools showed number of prey captures was highest for bighead carp followed by gizzard shad with lower capture rates for bluegill, golden shiner, and silver carp. Observations of prey and predator behavior were quantified in a 720-L aquarium and variation in anti-predator behavior explained relative differences in vulnerability to predation. Differences in vulnerability to predation may explain the greater invasion success of silver carp. Similar or higher vulnerability to predation of Asian carp compared to common native prey suggests that they may serve as viable prey for native predators mitigating the potential negative impacts on the native prey community.

Soft plastic fishing lures (SPLs) have recently gained attention as a potential source of pollution in aquatic systems. A number of anecdotal reports have suggested that discarded SPLs are being ingested by wild fish and causing health problems including mortality. Few studies have been conducted concerning the effects of SPLs on fish. We designed a laboratory study to determine the effects of ingestion of three different shapes and two different materials of SPLs on consumption by largemouth bass. No effects on consumption were observed except on the first day after SPL ingestion. In three trials with 30 fish, all largemouth bass were ultimately capable of expelling the lures from their bodies. Field data were also utilized to determine the occurrence of SPL ingestion by largemouth bass in the wild. In two Illinois lakes, occurrence rates of SPL ingestion were $< 1\%$. Bass sampled with SPLs in their stomach did not have significantly different body condition from fish that had not ingested SPLs. We conclude that discarded SPLs do not pose a significant threat to the health of largemouth bass. Nevertheless, we encourage efforts to responsibly dispose of SPLs in order to prevent pollution and any possible undiscovered consequences of their presence in the environment.

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Chapter 1: Introduction

The ability to learn is an important skill for many animals to develop in order to optimally interact with their environment. One of the most common applications of learning by animals is to optimize foraging. A number of aspects of foraging can be improved by learning including patch profitability and prey handling skills (Gotceitas and Colgan 1991; Croy and Hughes 1991). Learning of foraging skills becomes increasingly important in the presence of novel prey. Prey items are considered novel when the predator has not encountered it previously and is not accustomed to feeding on it.

Animals employ sampling behavior, consuming a variety of potential foods and evaluating their profitability (Clark 1982). When encountering novel prey, a predator will base its decision on whether or not to consume the prey based on its previous foraging experiences and aspects of the novel prey with which it is familiar. Predators will use aspects such as visual appearance and chemosensory cues to evaluate novel prey (Curio 2012). As experience with a novel prey increases, predators become familiar with it and begin to utilize that prey source more readily and efficiently (Godin 1978). Animals are also capable of learning about novel prey from conspecifics in social settings (Brown and Laland 2001; Page and Ryan 2006). Once a predator has become familiar with a previously novel prey it will have evaluated the profitability of that prey. A number of aspects of the prey can influence its profitability such as nutritional value, availability, handling time, and even toxicity (Bowen et al. 2002; Zwarts et al. 1996; Holen 2013). Knowing which prey is the most profitable one available will allow a predator to forage optimally and increase its overall fitness (Pyke 1984).

Fish are commonly used predators in studies of learning in novel foraging. There are a myriad of scenarios where fish might encounter profitable novel prey including terrestrial food sources, ontogenetic diet shifts, and non-native species (Sundström and Johnsson 2001; Olson 1996; Wagner 1972). Introduced species have likely not evolved to be able to avoid local predators and thus provide a profitable source of prey. This has occurred on multiple occasions in the Laurentian Great Lakes (Steinhart et al. 2004). Asian carp are relatively new invaders and spreading throughout the Mississippi River Basin. They are a potentially profitable novel prey but predation on them by native predators remains unstudied. Novel prey may also be harmful to predators. Toxic prey in particular can cause sickness or even death in predators which are not experienced with them and mistakenly consume them (Beckmann and Shine 2011). Anglers discard potentially toxic soft plastic fishing lures into rivers and lakes. These lures appear to be novel prey to fish and due to their realistic appearance and chemosensory profiles, fish may consume them. This would be a truly novel prey for fish, the effects of which have yet to be studied.

Chapter 2: Vulnerability of Juvenile Asian Carp to Predation by Largemouth Bass

Introduction

Asian carp, the general term for both Silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Hypophthalmichthys nobilis*), are invasive species in North America. Brought to the United States in the 1970's for aquaculture purposes and then escaping into the wild in the1980's, they are a relatively new invader of aquatic ecosystems (Williamson and Garvey 2005). These fishes are filter feeders and have the potential to negatively impact all species of native fish by decreasing plankton abundance (Radke and Kahl 2002; Lewkowicz and Lewkowicz 1992). With their populations rapidly increasing throughout the Mississippi river basin, there is concern that they will cause great damage to the ecosystems they invade (Chick and Pegg 2001). These concerns have prompted studies both in the United States and around the world focused on competitive effects of Asian carp invasion including topics such as trophic alteration, exclusion, and diet overlap with native species (Kolar et al. 2007; Sampson et al. 2009). Control of Asian carp populations has been investigated through piscicides, physical removal (e.g. through harvest), habitat alteration, and both physical and sensory barriers (Kolar et al. 2007; Sparks et al. 2011; Taylor et al. 2005). Another common method is biological control of invasive species (Messing and Wright 2006; Bajer et al. 2012) but biological control via predators has not been examined for Asian carp. In order to control an invasive species, an understanding its life history and knowledge of its potential weaknesses including vulnerability to predation are needed (Bailey and Houde 1989; Hansen et al. 1998). Asian carp are potentially harmful invasive species but we have a limited understanding of what drives the invasiveness of these fish in new environments (Kolar et al. 2007).

Previous assessments of predation on Asian carp are limited. A study from the former Soviet Union reported a number of piscivorous fishes including zander (*Sander luciperca*), northern pike (*Exos luscius*), Eurasian perch (*Perca fluviatilis*), and ide (*Leuciscus idus*) consumed juvenile bighead carp in aquaculture ponds (Negonovskaya 1980). In another aquaculture operation, African clawed frogs (*Xenopus laevis*) predated on larval and juvenile silver carp (Schramm 1987). It is likely that native predators in the United States consume juvenile Asian carp as they are morphologically and behaviorally similar to common native prey species such as gizzard shad (*Dorosoma cepedianum*) (Kolar et al. 2007). Vulnerability of Asian carp to predation relative to native prey species is unknown.

The largemouth bass is a native piscivore found throughout the Mississippi river basin where Asian carp have spread that predates heavily upon gizzard shad (Storck 1986) which juvenile Asian carp closely resemble (Page and Burr 1991). As a highly adaptable predator, the largemouth bass is capable of successfully foraging in a wide range of heterogeneous habitats from open water to dense vegetation (Savino and Stein 1989). Largemouth bass are capable of switching their foraging behaviors between cruising and ambushing in order to most efficiently feed on a wide variety of species and in a wide variety of habitats (Savino and Stein 1982). Prey selection by largemouth bass has been studied extensively including effects of prey species, size, and morphology as well as behavior and interactions with environment (Hodgson and Kitchell 1987; Howick and O'Brien 1983; Hambright 1991; Hoyle and Keast 1987; Web 1986; Savino and Stein 1982). It is unknown how these vulnerabilities and prey preferences are affected by unique characteristics of the invasive Asian carp such as the frequent jumping observed by silver carp (Green and Smitherman 1984).

Native predators can adapt to utilize non-native species. Non-native Eurasian milfoil (*Myriophyllum spicatum*) has been shown to facilitate piscivory in juvenile largemouth bass (Dibble and Harrel 1997). Largemouth bass have been found to feed preferably on blue tilapia (*Oreochromis aureus*) (Schramm and Zale 1985) and were shown to consume more common carp (*Cyprinus carpio*) and tilapia than they do some native prey species (Lewis and Helms 1964). Smallmouth bass (*Micropterus dolomieu*) have thrived on the invasive round goby (*Neogobius melanostomus*) in the Laurentian Great Lakes (Steinhart et al. 2004). Invasive alewives (*Alosa pseudoharengus*) are fed upon by a number of native species such as walleye (*Sander vitreus*), northern pike (*Esox lucius*), and bowfin (*Amia calva*). In some circumstances predators feed on invasives far more than native prey species and even increase predator growth (Wagner 1972).

In this study we investigate predation upon juvenile Asian carp, both bighead and silver, by largemouth bass and compare it relative to the vulnerability of several native prey species. The three native species used in the experiments, bluegill (*Lepomis cacrochirus*), golden shiner (*Notemigonus crysoleucas*), and gizzard shad (*Dorsoma cepedianum*), represent a wide range of morphologies and behaviors and are commonly found throughout the invaded range of Asian carp. Our objectives were to: assess the mechanisms driving vulnerability of juvenile Asian carp to predation by largemouth bass relative to native prey species; evaluate largemouth bass preference of prey between Asian carp and three native species; and determine whether or not Asian carp have any unique anti-predator behaviors which might affect their vulnerability to predation.

We hypothesize that, despite their taxonomic similarity, silver and bighead carp will display different behaviors and largemouth bass will exhibit different preferences for them. This hypothesis is based on observations of differences between the Asian carp species. Previous gear selectivity studies have found that bighead and silver carp are susceptible to different capture methods (Butler et al. 2014). Silver carp were caught in large numbers by electrofishing whereas bighead carp were rarely sampled indicating that silver carp are often located in the upper portion of the water column. Conversely, bighead carp were sampled by hoop nets, which are set on the bottom of the river, and silver carp were not. Silver carp also differ from bighead carp in their jumping behavior which may contribute to differences in vulnerability to predation.

Methods

Experiments were conducted at the Kaskaskia Biological Station, Illinois Natural History Survey, Sullivan, IL. Largemouth bass, bluegill, and gizzard shad were collected from local lakes and, bighead carp, silver carp, and golden shiners were obtained from hatcheries. All fish were acclimated to the lab environment for at least one month prior to experiments. Prey fish ranged from 45 to 75 mm in length and the largemouth bass ranged from 160 to 240 mm. In each trial prey were matched to each predator so that prey were of a vulnerable size that is close to the optimal size (~30% of predator length). At these sizes, both bluegill and gizzard shad optimal sizes overlap for largemouth bass (Hoyle and Keast 1987; Shoup and Wahl 2009). Largemouth bass were maintained on a diet of golden shiners in the laboratory during acclimation however, they were introduced to each prey species before experiments in order to help eliminate any learning bias. Both predator and prey were placed in tanks together and the largemouth bass were allowed to feed for 24 hours. The prey not consumed during these acclimation periods were then used in the experimental trials.

Prey selection experiments

Prey selection experiments were conducted in 2 m diameter pools filled to a depth of 45 cm, similar to those used in previous studies (Einfalt and Wahl 1997; Wahl and Stein 1989). Individuals (N = 5) of three different prey species were placed in the tank for a total of 15 prey. Experiments were conducted with three species groups in order to prevent predator swamping and due to the limited availability of some of the species. Two different three species combinations were devised to focus on two different objectives. The first species combination, bluegill, golden shiner, and bighead carp, compared two native species, one pelagic and one littoral as models representing a range of native species, to an Asian carp species. The other species group, gizzard shad, silver carp, and bighead carp, was a morphologically similar group comparing the vulnerability of both of the Asian carp species and the native species which is the most morphologically similar to Asian carp of the three native species examined in this study.

A single bass was placed in an opaque plastic container along the side of the tank that separated them from the prey. After a 6 h acclimation period, the bass was released to feed on the prey. The bass was allowed to forge for 24 h but the trail was terminated if more than 5 prey were consumed as prey choice may then have been confounded by availability (Einfalt and Wahl 1997; Shoup and Wahl 2009). At the end of the trial, fish were removed from the tank and the number of each prey species consumed was counted. A total of 20 different bass were tested with each of the prey groups.

Prey preference was calculated using Chesson's electivity value which is used when multiple prey types are offered, and individuals consumed are not replaced (Chesson 1983) given by the equation:

$$\hat{\alpha}_i = \frac{log_e\left(\frac{n_{i0}-r_i}{n_{i0}}\right)}{\sum_{j=1}^{m} log_e\left(\frac{n_{j0}-r_j}{n_{j0}}\right)}$$

where n_{i0} is the number of prey type *i* at the beginning of the experiment, r_i is the number of prey type *i* consumed by the predator, and m is the number of different prey types. α represents the relative preference for each prey species ranging from values of 0 to 1. The estimated values can then be centered on zero for interpretive purposes as:

$$\varepsilon_i = \frac{m\hat{\alpha}_i - 1}{(m-2)\hat{\alpha}_i + 1}$$

The value gives the relative selectivity for each prey type ranging from +1(always chosen) to -1 (always avoided) with 0 indicating no preference (Chesson 1983). Differences in prey preferences were tested using one-way ANOVA and Tukey's mean separation. Due to the large number of zeros in the data set for some species, the data did not fit the assumption of normality. As a result, the ANOVA was conducted using a generalized linear model fitted to an exponential distribution which provided the best fit.

Behavior experiments

Experiments designed to examine the mechanisms driving vulnerability of prey to predators were conducted in a 750-L rectangular glass observation tank (180 x 70 x 60 cm). Similar tanks have been used previously to evaluate predator-prey interactions (Einfalt and Wahl 1997) and the results reflected patterns observed in natural settings (Wahl and Stein 1988). The tank was divided into two separate areas by an opaque plastic panel. The smaller section was further divided into two predator holding compartments (30 x 35 cm) while the larger section (150 x 70 cm) served as an experimental chamber. The plastic divider had two openings in it covered by remotely operated doors which connected the predator holding compartments to the experimental chamber. Individuals (N = 10) of a single prey species were placed in the large experimental portion of the tank while a single largemouth bass was placed in the smaller holding compartment (Einfalt and Wahl 1997). All fish underwent a 24 h starvation period before the experiments in order to standardize hunger and feeding motivation (Webb 1986). Fish were acclimated to the experimental tank for 6 hrs prior to beginning each trial. Digital video was recorded during all trials and later analyzed in order to ensure accurate and detailed measurements. A series of dashes spaced at 5 cm on the experimental chamber helped to facilitate measurements.

Trials began with a 10 min period prior to the introduction of a predator that was used to observe prey behavior and compared with a 10 min observational period of prey behavior in the presence of a predator. During these 10 min periods, prey behavior was recorded in 1 min intervals. The behaviors recorded were; number of prey schooling (Three or more individuals moving as a unit) (Einfalt and Wahl 1997), the two dimensional size of those schools, and the distance between the predator and the nearest prey. A single bass was then released from the holding compartment via the remotely operated door and allowed to enter the experimental chamber containing the prey. Trials lasted for 45 min after the introduction of the predator and predation was never observed after 30 min. Data were recorded on a computer during this period using the event recording software Student BEAST 2005 (Windward Technology, Kaneohe, Hawaii) which tracked both the number of occurrences and the time elapsed for each event. Predator behavior was separated into five mutually exclusive categories, similar to those defined previously for other piscivores (Savino and Stein 1982; Wahl and Stein 1988): inactive (resting or moving slowing without any orientation towards prey); recognition (motionless, but oriented towards prey); follow (moving and orienting to prey); pursue (following at burst speed, normally resulting in a strike); and handling (prey was successfully captured). Number of strikes and successful captures and whether they were on schooled or dispersed prey were also recorded in order to calculate capture efficiencies. Additionally, the number of times prey jumped out of the water during pursuit was recorded as silver carp have been noted for their predisposition to jumping and it is possible that this behavior developed as predator avoidance (Green and Smitherman 1984).

Each largemouth bass (N = 20) was tested once with each prey species. Gizzard shad (N = 15) and silver carp (N = 17) were tested with fewer bass due to limited availability of those prey. Each bass was tested with each prey species within a two week in random order to avoid learning bias. Both predator and prey behaviors were analyzed using one-way analysis of variance (ANOVA) and differences in means determined using a Tukey's HSD test. An initial analysis used a generalized linear model with individual bass as blocks to account for any individual variation or timing of the trials however; the blocking effect was not significant and removed from final analysis.

Results

Prey selection

Largemouth bass captured a mean of 1.8 prey per trial during the prey selection experiments. Each largemouth bass captured at least one prey fish and one trial was terminated early after the largemouth bass consumed five prey items. In both prey combinations, bighead carp were the most preferred prey species. In the first prey combination trials, largemouth bass exhibited a significant ($F_{2,57}$ = 12.47, P = < 0.001) preference for bighead carp more than three times greater than for bluegill and golden shiner which both had similarly low selection rates (Figure 1.1). In the second prey group combination, bighead carp (α = 0.48) were preferred significantly ($F_{2,57}$ = 8.19, P < 0.001) more than gizzard shad (α = 0.35), which were preferred significantly more than silver carp (α = 0.17). Both species of Asian carp commonly schooled together and often with gizzard shad. Golden shiner and bluegills when schooled were almost exclusively with conspecifics.

Behavior

During the prey vulnerability experiments, the mean number of each species captured per largemouth bass (1.4) was not significantly different (Table 1.1; $F_{4,87} = 0.25$, $P = 0.91$). The largest number of prey items consumed in a trial was 3 and at least one prey item was consumed in all trials. No significant differences were observed in the amount of time spent following or pursuing each captured prey species (Table 1.1). Combining these two behaviors into one to measure, the amount of time spent foraging to capture one prey item was similar among prey species (Table 1.1). Significant differences did exist in the efficiency (captures/strike) with which largemouth bass predated on each species (Figure 1.2; $F_{4,87} = 3.79$, $P = 0.007$). Bighead carp were captured at a higher efficiency than bluegill, golden shiner, and silver carp with gizzard shad intermediate but not significantly different from these two groups (Figure 1.2). Once captured, handling time of the prey was slightly longer for the two deeper bodied species, bluegill and gizzard shad, but was not significantly different (Table 1.1) ($F_{4,87} = 0.72$, $P = 0.58$).

A number of significantly different behaviors were observed among the prey species that may explain differences in capture efficiency. All species employed jumping as an anti-predatory behavior during the trials. Bighead carp only very rarely jumped (Figure 1.3), significantly less than golden shiner and gizzard shad ($F_{4,87} = 3.22$, $P = 0.02$). Both bluegill and silver carp jumped at rates that were intermediate to the others (Figure 1.3). The distance each prey species kept from the predator was also significantly different ($F_{4,87} = 2.83$, $p = 0.03$). Gizzard shad remained closest to the largemouth bass (33.4 cm ± 4.4) and golden shiner the farthest (51.1 cm ± 3.8) with bluegill, bighead carp, and silver carp all being intermediate (Table 1.1). Schooling behaviors of the prey species also differed. Bluegills were the only prey species that did not exhibit consistent schooling behavior in the absence of a predator. Once a predator was introduced to the tank, the majority of the prey for all species were schooled in the presence of the predator. Bighead carp formed significantly smaller schools than bluegill, gizzard shad, and silver carp whereas golden shiners formed schools of an intermediate size (Figure 1.4). Bighead carp were the only prey that failed to modify their schooling behavior in the presence of a predator; their mean school size did not change significantly ($P = 0.20$). Bluegill increased from schooling rarely to being schooled all of the time in the presence of the predator. Golden shiner (34% ± 9.7), gizzard shad (23% ± 14), and silver carp (52% ±11) all increased their school sizes with a predator present. Largemouth bass typically captured more dispersed prey than schooled prey. Silver carp ($P = 0.24$) and bighead carp ($P = 0.12$) were the only two species which did not have a significantly greater number of individuals captured when they were dispersed than when in a school.

Discussion

Despite failing to exhibit any unique anti-predatory behaviors, silver carp were not highly selected as prey by largemouth bass; being selected less than bighead carp or gizzard shad. Silver carp were similarly selected by largemouth bass as bluegill and golden shiner, both species that are heavily exploited as prey by largemouth bass (Noble 1981). Bluegill have been commonly found to be a low vulnerability prey species with a variety of predators (Lewis and Helms 1964; Einfalt and Wahl 1997; Wahl and Stein 1988). Bighead carp were the most vulnerable species overall and were selected even more than gizzard shad which are commonly utilized as prey by most piscivorous fish throughout their range (Nobel 1981) and, in many studies of predation, have been shown to be the most vulnerable and preferred prey (Einfalt and Wahl 1997; Wahl and Stein 1988).

The prey selection experiments showed a strong pattern of bighead carp being the most vulnerable species. In both the prey species combinations, bighead carp were selected most often. In comparison, other species were avoided in the presence of bighead carp. Silver carp were the least preferred species in the second prey species combination, indicating that there is a difference in preference between the two Asian carp species. Patterns of capture efficiency were similar to those observed for prey selection. Largemouth bass were able to capture bighead carp with more than twice the efficiency of silver carp, bluegill, and golden shiner. Bighead carp were captured with similar efficiency as gizzard shad.

A number of prey behaviors may help explain patterns of prey selection. Even though the efficiency with which prey were captured did differ among prey species, time spent following and pursuing prey did not explain differences in vulnerability to predation or prey selection. Predators that are foraging optimally will preferably consume prey that require less effort to pursue as, all else being equal, they are the most vulnerable (MacArthur and Pianka 1966; Griffiths 1980). However, follow and pursuit are often short and may be relatively unimportant parts of the predation sequence (Beauchamp et al. 2007). In previous studies, prey that maintained greater distances from predators were attacked significantly less (Savino and Stein 1982; Savino and Stein 1989) and our results support these findings. Distances that prey maintained from largemouth bass in our study differed between gizzard shad and golden shiner with gizzard shad maintaining the shortest distances and being preferred prey. Handling time for the deeper bodied species was greater, but not significantly so, indicating that morphology did not play a major role in vulnerability and preference as has been demonstrated in previous studies (Hoyle and Keast 1987; Nilsson and Brönmark 2000), but rather prey behavior was more important. Contrary to our hypothesis, silver carp did not jump more than the other species. The jumping commonly observed by the adults of this species (Green and Smitherman 1984), may not originate from innate anti-predatory behavior. Bighead carp rarely jumped, representing another way bigheads failed to use anti-predatory behaviors that other species employed.

Schooling behavior may also play a role in the vulnerability of Asian carp. Bighead carp formed the physically smallest schools. Previous work has linked tighter schooling to decreased vulnerability to predation (Magurran and Pitcher 1987) however; once a predator was introduced, bighead carp were the only species that failed to modify their schooling behavior. Bluegills went from little schooling to constant schooling, while golden shiner, gizzard shad, and silver carp all significantly increased the physical size of their schools. Bluegills were captured most when dispersed indicating schooling was an effective anti-predator strategy. Largemouth bass have demonstrated similar patterns of bluegill capture (Savino and Stein 1982). In contrast, bighead carp were captured most when schooled. Bighead carp may be more vulnerable when schooled or it may be an artifact of them always remaining in tight schools. Regardless, bighead carp failed to exhibit behavioral modifications in reaction to predation as did the other prey species. We attribute the increase in school size of golden shiner, gizzard shad, and silver carp to more energetically costly predator evasion behaviors (i.e. flash expansion) which are only exercised when actually being attacked (Magurran and Pitcher 1987). These behaviors involve burst speed swimming by individual prey in order to evade capture resulting in a fountaining effect of the school. These behaviors can confuse predators but increases the size of schools and the likelihood of individuals becoming separated from the school (Partridge 1982).

The observed differences in vulnerability between bighead and silver carp may play a role in their invasion success. Both species of Asian carp are highly fecund and fast growing (Williamson and Garvey 2005; Kolar et al. 2007) but predation, especially in combination with factors such as limited spawning habitat or food, may play an important role in their recruitment. High levels of predation upon juveniles may limit their recruitment in some areas. Conversely, the relatively lower vulnerability of silver carp may contribute to their ability to thrive throughout their invaded range. Regardless of their relative vulnerabilities, predation may play a role in limiting the spread of both species in areas with diverse and abundant predator populations.

Concern exists that Asian carp will outcompete native planktivores, many of which serve as forage species, reducing their populations and decreasing the available prey for native predators (Kolar et al. 2007; Sampson et al. 2009). Due to their high vulnerability, bighead carp may serve to mitigate impacts on native predators resulting from the displacement of native forage species by Asian carp. At high densities, silver carp also have the potential to serve as an alternative food source for native predators. High densities of juvenile Asian carp could also serve as an abundant and easily utilized prey source increasing predator growth.

Ours is the first study to examine predator-prey interactions between invasive Asian carp and a native predator. Although largemouth bass are widespread, versatile, and commonly found in the same habitats that juvenile Asian carp are believed to utilize (Kolar et al. 2007), a number of other piscivorous species may also utilize Asian carp. Understanding the ability of species such as walleye, catfish, or white bass to feed on Asian carp may be useful if biocontrol is to be part of an integrated pest management plan or when modeling Asian carp invasion and population dynamics. Examination of how environmental variables such as vegetation, turbidity, or current affect the vulnerability of Asian Carp to predation would also be useful. Our results indicate that native predators are likely feeding on juvenile Asian carp. Field studies will be necessary to verify these assessments and to determine what predatory pressure Asian carp populations are actually experiencing throughout their range. Understanding predator-prey interactions between Asian carp and native predators will contribute to understanding how to control these highly invasive species.

Chapter 3: Effects of Ingestion of Soft Plastic Fishing Lures on Largemouth Bass

Introduction

Recreational fishing has been growing in popularity in the United States over the last few decades (USFWS, 2012). Although much of the focus on the effects of angling has been directed towards harvest, there has also been an increasing interest in effects such as environmental degradation via pollution and physical disturbance (Cooke and Cowx 2006; O'Toole et al. 2009). A number of studies have shown that recreational fishing gear including line, hooks, and lead weights, are discarded by anglers and can have negative impacts on the animals that come in contact with these materials (Jones 1995; Franson, et al. 2003). A study conducted on several Minnesota lakes estimated the amount of fishing gear lost by anglers and found that approximately one metric ton of lead fishing gear was lost on five lakes annually, highlighting the potential for significant amounts of litter produced by recreational angling in aquatic systems (Radomski, et al. 2006). As participation in recreational fishing increases, it is reasonable to assume that these adverse effects on the environment will also increase.

Accompanying the growth of recreational angling over the last several decades is a relatively new source of fishing gear pollution, soft plastic lures (SPLs). In Charleston Lake Ontario, Canada, the deposition rate of SPLs was estimated to be as high as 80 SPLs per km of shoreline per year (Raison et al. 2014). These popular lures are extremely versatile and appeal to a number of fish species as they can be molded into many shapes and impregnated with chemostimulants, mimicking natural prey. SPLs are often used as substitutes for live bait because they are more durable, eliminate keeping live bait alive, and offer an alternative when regulations forbid live bait. There are a myriad of companies producing SPLs but the vast majority of SPLs are made out of some combination of polyvinylchloride (PVC) and plasticizers, are not degradable, and likely cannot be digested by fish (Bowles 1994; Danner et al. 2009). A handful of these companies are producing what they market as “natural” or “biodegradable” lures which are an environmentally friendly alternative to PVC SPLs (Berkley, Big Bite Baits, Food Source).

One disadvantage of SPLs is that they are not especially durable relative to other lure types due to the plasticizers rendering them soft and pliable. After extended use, or after catching fish, they will eventually tear and become unusable. Some anglers will then discard these unusable SPLs into the water, without considering environmental impacts. In addition to being discarded by anglers, SPLs can also be introduced to the environment when fish tear them off the hook, either when they initially take hold of the lure or as anglers are fighting them. Due to their life-like appearance and appealing scent and taste, fish may ingest these discarded lures, mistaking them for natural prey items.

Fish have been known to ingest foreign objects, presumably misidentified as prey, in the wild (Sundström and Johnsson 2001). A popular angling method, commonly referred to as “dead sticking,” relies on fish picking up the lure as it sits motionless on the bottom. Therefore, it is not unreasonable to assume that fish might ingest SPLs sitting in on a lake or stream bottom. There have in fact been a number of cases where it has been observed that wild fish have ingested SPLs, occasionally multiple SPLs (Danner et al. 2009). Raison et al. (2014) found that 2.2% of gillnetted lake trout and 3.4% of angled smallmouth bass had SPLs in their stomachs. They also found that 59.5% of interviewed anglers who had harvested lake trout reported finding at least one SPL in lake trout stomachs.

Once ingested, fish are likely not able to digest SPLs. Due to the complex shapes of these lures, it may be difficult to pass the lure through the digestive system. Many SPLs are heavily impregnated with salt causing the lure to absorb water and expand. SPLs have been shown to increase in length by up to 120% (Raison et al. 2014). Expanded size may increase the chance of it becoming lodged in the digestive track and forming a gastric bezoar, a mass in the stomach which can cause gastric obstruction, ulceration, hemorrhaging, and perforation (Filipi et al. 1995). Bezoars can be formed by a number of materials including hair, undigested food, and foreign objects. Wild animals have been known to ingest foreign objects, often litter from humans. Turtles, seals, and over 100 species of birds have been known to consume plastic debris, often resulting in mortality (Gregory 2009). Waterfowl in freshwater also consume discarded tackle occasionally causing lead poisoning (Radomski et al. 2006) and fish may also be similarly affected by discarded materials. The plasticizers used in manufacturing SPLs are often phthalates, known endocrine disruptors which are not chemically bound to the PVC and can leach into water (Heudorf et al. 2007). Phthalates have been shown to have toxic effects on freshwater fish including alteration in enzyme activity and mortality (Ghorpade et al. 2002).

The potential threat of SPLs to fish health has not gone unnoticed. Popular angling magazines and topics on online angling forums often discuss the perceived threat and negative impacts discarded SPLs might be having on sport fish. Severely emaciated fish have been found with a mass of soft plastic lures in their stomachs. Legislation was proposed to ban the use of SPLs, including biodegradable versions, in the state of Maine (HP0037 2013), but there is currently very little scientific evidence to make a decision regarding banning SPLs.

Despite a large amount of anecdotal evidence, public interest, and a need for information for legislative purposes, there has only been one study conducted on the effects of soft plastic fishing lure ingestion on fish (Danner et al. 2009). Unfortunately, the conclusions of this study are of a limited value as the authors admit it was an unreplicated study “without strict experimental research methodology" (Danner et al. 2009). They used juvenile domestic and wild strain brook trout (*Salvelinus fontinalis*) from a hatchery that were repeatedly fed a number of SPLs weekly for 90 days. Fish fed SPLs had gastric bezoars at the end of the study and, as a group, lost a significant amount of weight when compared to the control. A decrease in the body condition of the fish could have negative implications for a number of aspects of fish health including growth and reproduction. These results provide evidence that SPL ingestion could, in fact, have detrimental effects on fish and highlight the need for further investigation.

We examined the possible effects ingestion of SPLs may have on adult largemouth bass (*Micropterus salmoides*). Largemouth bass were chosen as the study species due to their widespread geographic range and the fact that most SPLs are designed for black bass (*Micropterus spp.*) angling. We conducted laboratory and field studies in order to develop a more comprehensive idea of how wild fish might be affected by SPLs and how these effects might differ with regard to SPL size, shape, and composition. The objective of the laboratory study was to determine the effects of SPL ingestion at the individual level where as the field study sought to document the occurrence of SPL ingestion in a wild population of largemouth bass.

Methods

Laboratory

Largemouth bass (N=40) were collected from central Illinois lakes using DC electrofishing gear during summer 2013. These fish were of a size targeted by anglers (Gabelhouse and Willis 1986) and were large enough to consume SPLs (357mm ± 19mm SD). Fish were transported to the Kaskaskia Biological Station, Sullivan, IL, where they were held individually outdoors in identical 1.5 m diameter plastic circular tanks filled to a depth of 50 cm. Tanks were aerated to ensure sufficient dissolved oxygen levels. Each fish was measured, weighed, and had its stomach pumped via gastric lavage (Foster 1977) to confirm that it did not already have a SPL in its stomach. All fish were held for at least two weeks to acclimate before use in the experiment. During this time fish were fed golden shiner (*Notemigonus crysoleucas*), ad libitum and their feeding behavior was observed in order to identify any potentially sick or injured fish and ensure that all fish behaved naturally.

The experiment was designed as a two factor factorial with SPL shape and material as main effects. Fish (n=10) were randomly assigned to six treatment combinations of shape and material. Three SPL shapes/sizes were used; a 10 cm boot tail shad, an 18 cm ribbontail worm, and a 10 cm finesse worm (Table 2.1). The shad shape was largest in mass and shape, followed by the ribbontail worm and then the finesse worm. Two material treatments were used within each shape treatment, a non-biodegradable lure and a biodegradable one. Three temporally discrete trials with each shape were conducted. Each material treatment was present in each shape trial. In each trial, treatments were randomly assigned to individual fish from the original pool of n = 40 fish. Individual control fish (n=10), which had not ingested a lure, were run during each trial. The data from the controls were analyzed as a one-way ANOVA using the single factor time and demonstrated the fact that there was no effect of time on any measured variable.

Food was withheld for 24 h prior to the start of the experiment in order to standardize hunger. Each fish was then fed a SPL according to its assigned treatment. In the first trial using the shad shaped SPL, fish were force fed the lure as it was too time consuming to get all of the fish to ingest the lures voluntarily and maintain a cohesive start time. The control went through a simulation of force feeding in order to standardize any handling effects. A subset of fish (N = 6) voluntarily consumed the shad shape SPL and their average consumption did not differ from those that were force fed (P = 0.79). All fish in the ribbontail worm and finesse worm treatments voluntarily ingested the SPLs. The majority of fish in these trials ingested lures as soon as they were introduced to the tank. For a minority of fish (20%) the SPL was attached to a length of monofilament fishing line via a small metal clip and was allowed to slowly sink to the bottom of the tank. The movement of the SPL then triggered the bass to strike. Once the bass had captured the SPL, the fishing line was pulled and the metal clip slipped out. Once a fish captured a SPL, it was ingested and none of them were immediately rejected.

Immediately after SPL treatments were applied, bass were fed golden shiners ad libitum. Shiners were weighed in batches of 50 individuals in order to calculate the average weight of a shiner for each day. Bass were observed a minimum of three times per day to replace consumed shiners, attempting to maintain a target of 10 shiners in each tank. At the end of each day the number of shiners left in the tank was counted and subtracted from the number fed that day to determine the total number consumed. Number consumed was then multiplied by the average weight per shiner for that day and divided by the weight of the bass to calculate relative consumption (Deboom et al. 2010). Consumption was monitored for each fish until they expelled the SPL. Number of days from ingestion to expulsion was recorded for each fish.

All data were tested for homogeneity of variances and normality. Cumulative average daily consumption during the time the fish retained the SPL was estimated after day one and again after the first week (see results for details on why experiment was truncated after one week). These two time periods were analyzed as two-way ANOVAs. A general linear model, containing the two fixed factors shape and material, was fitted to the data. Time until expulsion of lures did not meet the assumptions of ANOVA. As a result, a generalized linear model was fitted to the data with the lognormal distribution and analyzed using the glimmix procedure in SAS. Tukey's tests were used to determine statistically significant differences between treatment groups. Difference of consumption from the average of the control fish over all time periods was analyzed for all treatments using t-tests.

Field

Consumption of SPLs was examined in two Illinois lakes. The first, Ridge Lake, is a 5.6 hectare lake located in Fox Ridge State Park, Illinois. The lake is open to controlled angling by the public and one of the most popular species targeted there is largemouth bass. The public is allowed access to the lake from 14:00 to 20:00, Thursday through Sunday, from Memorial Day until Labor Day. There is a complete creel survey in place on the lake where all anglers pass through a single entry point so that they can be counted and surveyed. All angling is done from john boats kept at the entry point and every fish caught is kept in a livewell until the creel clerk is able to measure and weigh it. Electrofishing around the entire perimeter of the lake is also used to survey largemouth bass, which are then measured and weighed (Santucci and Wahl 1991). Diet data were collected annually from 2005 to 2013. Stomach contents of all fish sampled were removed with clear acrylic tubes which allowed for visual confirmation that the stomach was emptied (Van Den Avyle and Roussel 1980). Lengths and weights measured from sampled fish were used to calculate condition factors for fish found with and fish found without SPLs in their stomachs. The condition factor was calculated using the equation

$$K = 100 \cdot WL^{-3}$$

W being total mass (g), L being total length (cm), and 100 being a scaling factor (Ricker 1975). Condition factor was compared via t-test between fish sampled with and without SPLs in their stomachs. These data on the prevalence of SPL ingestion in Ridge Lake were supplemented with one year of diet samples obtained from Lake Mingo in 2001. Lake Mingo is a 68 hectare lake located in Kennekuk County Park, IL. The lake is open to the public and anglers often target largemouth bass. Bass for the study were collected by electrofishing and their diets sampled by tubing in the same manner as in Ridge Lake.

Results

Laboratory

After the first day, food consumption was significantly affected by both the shape ($F_{2,54}$ = 10.29, P < 0.001) and material ($F_{1,54}$ = 12.44, P < 0.001) of the SPLs. There was no significant interaction between the shape and material ($F_{2, 54}$ = 1.77, P = 0.18). Fish ingesting the shad shaped plastics consumed the least amount of food followed by the ribbon tailed worm and finesse worm (Figure 2.1). Of these SPL shapes, only fish ingesting the shad shape lure consumed significantly less than the control fish (P = 0.02). Within the material treatment, largemouth bass ingesting the biodegradable lure ate less on the first day than the fish fed a non-biodegradable lure (P = 0.004). Consumption by largemouth bass having ingested the biodegradable lure was significantly lower than the control fish (P = 0.03), but was similar between the non-biodegradable lure and the control (P = 0.58).

Differences in consumption observed on the first day after ingesting SPLs did not persist through the first week of the experiment. During the first seven days, neither the shape ($F_{1, 36}$ = 3.11, P = 0.09) nor the material ($F_{1,36}$ = 0.79, P = 0.38) treatment had a significant effect on average daily consumption. There was also no interaction between the two treatments ($F_{1, 36}$ = 1.00, P = 0.32). Consumption in all treatments was not significantly different from the controls over the first week (Figure 2.2). Differences in consumption were also examined for individual days on days two through six and no significant differences were found on any day after day one.

Every fish that ingested a SPL in the study ultimately expelled it. The majority of the time this was by regurgitation but in two cases, the fish passed finesse worms (the smallest size of lure used) through their digestive systems. The shape treatment had a significant effect on the retention time of SPLs ($F_{2, 54}$ = 66.48, P < 0.001). The larger the SPL was the sooner the fish expelled it with retention time of the shad shape the shortest (1.96 d) followed by the ribbontail worm (9.24 d) and longest for the finesse worm (19.76 d) (Figure 2.3). The effect of the material treatment was also significant ($F_{1, 54}$ = 4.170, P = 0.046) with fish that had ingested a non-biodegradable lure expelling it on average 1.8 days sooner than those that ingested biodegradable lures (Figure 2.3). Each shape of SPL had at least one fish that retained the lure for at least 30 days. There were a total of four lures retained longer than 30 days, the longest of which was a finesse worm retained for 52 days before it was regurgitated.

Field

From 2005 through 2013 in Ridge Lake, 903 largemouth bass were sampled for diet contents from both electrofishing and creel surveys. Of these fish, five were found to have a SPL in their stomach resulting in an estimated occurrence of 0.55%. All of the fish found to contain a SPL were sampled via the creel survey. Condition factor did not differ between fish with a SPL (Mean = 1.187 SD = 0.11) and without a SPL (Mean = 1.319 SD = 0.211) (P = 0.21). An additional 477 bass were sampled for stomach contents from Lake Mingo. Of those fish, three were found to have a SPL in their stomachs for an occurrence rate of 0.63%.

Discussion

The potential for negative effect of SPLs discarded into the environment has become a topic in popular sport fishing magazines (eg. B.A.S.S. Times; available at http://www.bassmaster.com/news/dont-discard-soft-plastics-they-can-kill, and Field and Stream). Anecdotal evidence has led to legislation being proposed in the state of Maine to ban them (HP0037 2013). Previous studies have indicated a potential for SPLs to have detrimental effects on wild fish. Both smallmouth bass and lake trout in a Canadian lake have been shown to voluntarily ingest SPLs (Raison et al. 2014) and the only paper to study the effects of ingesting SPLs might have on fish provided some evidence that SPL ingestion may decrease body condition of juvenile brook trout (Danner at al. 2009).

We found that both the shape and material of SPLs had an effect on consumption of largemouth bass, but only on the first day following the ingestion of a SPL. Bass ingesting the shad shape and biodegradable lures exhibited significantly lower consumptions rates than control fish on the first day. Our results differ from previous research that found a decrease in body condition of juvenile brook trout fed SPLs over three months (Danner et al. 2009). Danner et al. (2009) repeatedly fed a variety of lures to the study fish through time. Fish may have regurgitated lures and then ingested others and a small difference in consumption, as we observed in day one of our study, repeated over three months may have been enough to cause a difference in growth for fast growing juvenile fish. Their study was unreplicated and the treatments were applied to only one group of fish in aggregate, limiting potential inferences that can be made from it.

The vomiting reflex is present through all levels of vertebrates and serves as an important defense against food poisoning and aids in ridding the stomach of foreign objects (Horn 2008). If a fish were to ingest a foreign object which irritated it, limited its ability to feed, or was not digestible, it would be expected to regurgitate that irritant (Sims et al. 2000; Sims and Andrews 1996). Regurgitation has been documented in a number of species including largemouth bass and can be induced with emetics which are chemicals that cause nauseous reactions (Jernejcic 1969; Tiersch and Griffith 1988). All of the fish that ingested lures in our study ultimately expelled them from their bodies. The overwhelming majority of fish regurgitated the lures, however two were able to pass the smallest sized lure all the way through their digestive systems. The largest bait was retained for the shortest amount of time whereas the smallest size was retained the longest. Retention times combined with fish ingesting the largest bait eating the least on the first day suggests larger lures are likely more irritating to the fish. The biodegradable lure also caused fish to eat less and regurgitate faster. Biodegradable lures may also be more irritating to fish, perhaps because of a chemical component acting as an emetic that is not present in the non-biodegradable lures. Biodegradable baits are advertised to release chemostimulants at a greater rate than the non-biodegradable and perhaps other components are leaching out at a greater rate.

In addition to examining SPL ingestion in the laboratory, we conducted field sampling to obtain an estimate of the occurrence of SPL ingestion in wild largemouth bass. We documented ingestion of SPLs on both of the water bodies sampled however; the rate of occurrence was relatively low (< 1% of fish sampled). Occurrence of ingestion of SPLs was also found to be low for smallmouth bass in the field (~3%) (Raison et al. 2014). Occurrence was slightly higher in smallmouth bass than in largemouth bass but both were still relatively low and one would expect that rates would differ between bodies of water. A number of factors, such as lake morphology and fishing pressure, could likely influence the rate at which fish encounter SPLs in their environment. Largemouth bass sampled with SPLs in their stomachs did not have a significantly different body condition than fish sampled without SPLs. Our sample size was small but none of the fish sampled were visibly emaciated as many anecdotal observations have reported. Based on our laboratory results and the simple morphology of a largemouth bass' digestive tract, we do not believe we missed any lures stuck in the intestines as most lures would be too large to enter and those that did in the lab study passed all the way through.

SPLs have reportedly been ingested by salmonids more often than by largemouth and smallmouth bass but ingestion rates from lake trout in Maine (5.2%, 3.2%, and 0.4%) (MDIFW 2014) and Ontario (2.2%) (Raison et al. 2014) were similar to that found for smallmouth bass (~3%) (Raison et al. 2014) but slightly higher than largemouth bass in our study. Many anecdotal reports from anglers of SPL ingestion are from lake trout with over half of the anglers interviewed having harvested a lake trout finding SPLs in a stomach on at least one occasion (Raison et al. 2014). It is unclear if salmonid species actually ingest SPLs more often than largemouth bass or perhaps differences in the salmonid digestive tract does not allow easy regurgitation.

It is unclear how often fish actually encounter and ingest SPLs in the wild. Our results indicate that they are capable of ingesting and are able to regurgitate any inadvertently ingested lures. Lures found in fish should not stay there for long which was supported by our low incidence in the field. Perhaps the small percentage of fish being witnessed in the field represents the rare individuals shown in our laboratory study to retain a lure for a long period of time. Most reports indicate that fish found having ingested SPLs often consumed multiple lures with the lures exhibiting signs of a lengthy retention and the fish themselves are in poor physical condition. We can only speculate as to whether these fish are in poor condition because of the lure or if they consumed the lure due to their poor condition. A sickly or starving fish may be more likely to ingest multiple lures that it perceives as easily caught food. A sick or poorly conditioned fish may also not react the same way as a healthy fish in regurgitating the lure. All of the fish used in our study were healthy and were able to expel the lures from their bodies without any apparent effect on their feeding.

We did not find any significantly negative impacts of SPL ingestion on largemouth bass. There was no decrease in feeding after the first day of SPL ingestion and all lures were ultimately expelled. Additionally, field data showed that the occurrence of SPL ingestion by wild fish is less than 1% of the population. Based on these results, we believe that discarded soft plastic fishing lures do not pose a significant threat to the health of largemouth bass. However, SPLs should still be discarded in a responsible manner. SPLs are a form of pollution and may have larger effects on other vertebrate species such as birds and reptiles. We support the conclusions of Raison et al. (2014) that anglers should be educated on responsible disposal of SPLs. Increasing public awareness should be made of the number of lures that are discarded into the environment. Education outreach by agencies or retailers and manufacturers should highlight proper disposal or recycling of the lures. SPLs can also fall off of hooks and anglers should attempt to rig the lures in such a way that minimizes these losses. Finally, manufacturers should be encouraged to develop biodegradable lures to replace the standard polyvinylchloride ones currently available. Biodegradable lures in our study were also regurgitated faster than standard SPLs providing an additional benefit. The long lifecycle of SPLs in aquatic systems could be a concern if there are any other consequences for their presence in the environment.

Chapter 4: Overall Summary

Despite their prevalence and potential for negative impacts, to date, there has been no assessment of vulnerability to predation of Asian carp. My study sought to examine largemouth bass predation on juvenile bighead and silver carp in relation to a number of common prey species. Prey species preference experiments were conducted in 2-m pools and showed number of prey captures was highest for bighead carp. Largemouth bass were also relatively successful at capturing gizzard shad but had lower capture rates for bluegill, golden shiner, and silver carp. Observations of prey and predator behaviors were quantified in a 720-L glass tank. The success with which largemouth bass were able to capture prey in these experiments was similar to that from the prey species preference experiments. A number of patterns observed in anti-predator behavior helped to explain relative differences in prey species vulnerability to predation. Bighead carp were found to be the most vulnerable species to predation overall; even more so than gizzard shad which are commonly found to be a particularly vulnerable native species. Silver carp in contrast were relatively less vulnerable to predation although likely not less vulnerable than bluegill or golden shiner. The differences in vulnerability to predation between bighead and silver carp may relate to greater invasion success of silver carp. The similar or higher vulnerability to predation of Asian carp compared to common native species suggests that they may serve as viable prey for native predators mitigating the potential negative impacts on the native prey community. In environments with robust predator populations, recruitment of Asian carp may be limited by predation.

A number of anecdotal reports have suggested that discarded SPLs are being ingested by wild fish and causing health problems including mortality. Few studies have been conducted concerning the effects of SPLs on fish. A single study has documented the ingestion of SPLs by wild lake trout and smallmouth bass. I designed a laboratory and field study to determine the prevalence and effects of SPL ingestion on wild largemouth bass. Largemouth bass were chosen because they are the species that are most targeted by anglers using SPLs and they are widely distributed throughout the country. In the laboratory study, three different shapes and two different materials of SPLs were fed to largemouth bass. In all trials fish were ultimately capable of expelling the lures from their bodies. The majority of these fish regurgitated the lures but two of them were able to pass the smallest sized lure all the way through their body. The larger the lure, the less time it took for the largemouth bass to expel it. Biodegradable lures were also expelled more quickly than lures made from PVC. Consumption of food was recorded while fish held and ingested lure but no effects on consumption were detected except on day one of the experiment. On day one, fish ingesting the largest sized lures consumed slightly less food than control fish. Field data was also utilized to determine the prevalence of SPL ingestion by largemouth bass in local lakes commonly targeted by anglers. In two Illinois lakes, occurrence rates of SPLs was < %1. Bass sampled with SPLs in their stomach did not have significantly different body condition from fish that had not ingested SPLs. The low rate of ingestion and the ability of the fish to expel SPLs from their bodies leads me to conclude that discarded SPLs do not pose a significant threat to the health of largemouth bass populations. Nevertheless, I encourage efforts to responsibly dispose of SPLs in order to prevent pollution and any possible undiscovered consequences of their presence in the environment.

Chapter 5: References

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Chapter 6: Tables and Figures

Table 1.1. Comparisons of mean values associated with vulnerability experiments for each prey species. Asterisks represent statistically significant differences in school size whereas different letters represent significant differences for the behaviors.

Behavior	Prey Species				
	Golden Shiner	**Bluegill**	**Gizzard Shad**	**Bighead Carp**	**Silver Carp**
Captures (#/trial)	1.4±.15 z	1.3±.15 z	1.4±.17 z	1.5±.15 z	1.4±.16 z
Following (sec.)	71.5±29 z	113.4±29 z	153.5±33 z	166.4±29 z	111.9±31 z
Pursuing (sec.)	59.7±15 z	72.3±15 z	49.6±17 z	47.9±15 z	55.5±16 z
Handling (sec.)	81.4±16 z	95.3±16 z	129.8±19 z	86.1±16 z	81.3±18 z
Bass foraging (sec.)	130±19 z	231±63 z	203±37 z	235±51 z	167±39 z
Distance from predator (cm)	51.0±3.9 z	45.4±3.9 yz	33.4±4.4 y	47.6±3.9 yz	41.6±4.1 yz
Change in school size (%)	34±9.7*	n/a	23±14*	6±12	52±11*

Table 2.1. Soft plastic lures used for each treatment combination of shape and material.

	Shape		
Material	**Shad**	**Ribbon**	**Finesse**
Non-biodegradable	4" Berkley Powerbait Ripple Shad	7" Berkley Powerbait Power Worm	4.5" Fat Roboworm (trimmed to 4")
Biodegradable	4" Berkley Gulp! Ripple Shad	7" Berkley Gulp! Turtle Back Worm	4" Berkley Gulp! Alive! Crawler

Figure 1.1. Comparison of means (± SE) from prey selection experiments organized by prey groups as tested. α is Chesson's selectivity value indicating relative selection of each species. The higher the value, the more preferred the prey. Different letters indicate statistically significant differences.

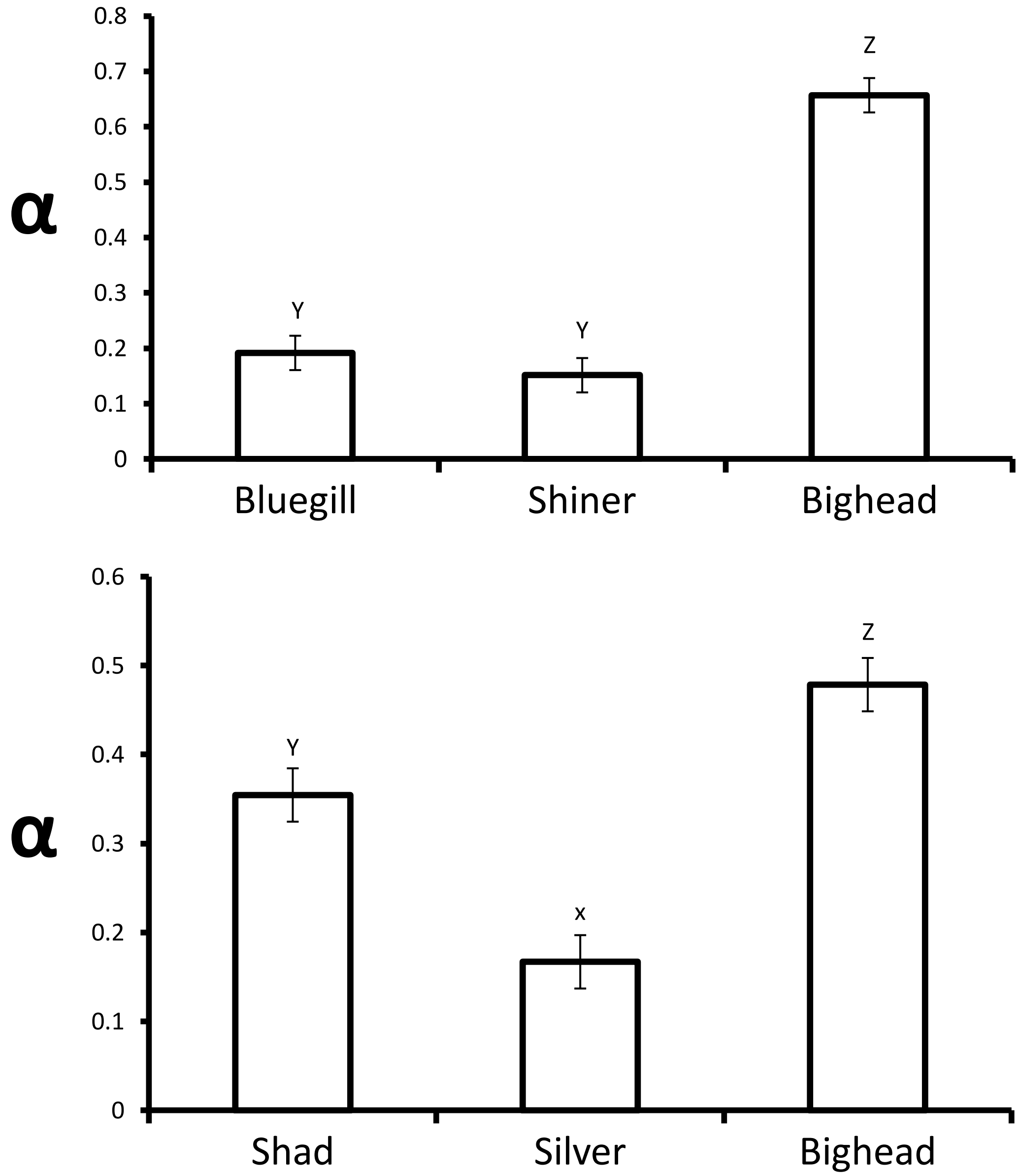

Figure 1.2. Mean capture efficiency (± SE) with each prey species; golden shiner, bluegill, gizzard shad, bighead carp, and silver carp. Different letters represent statistically significant differences.

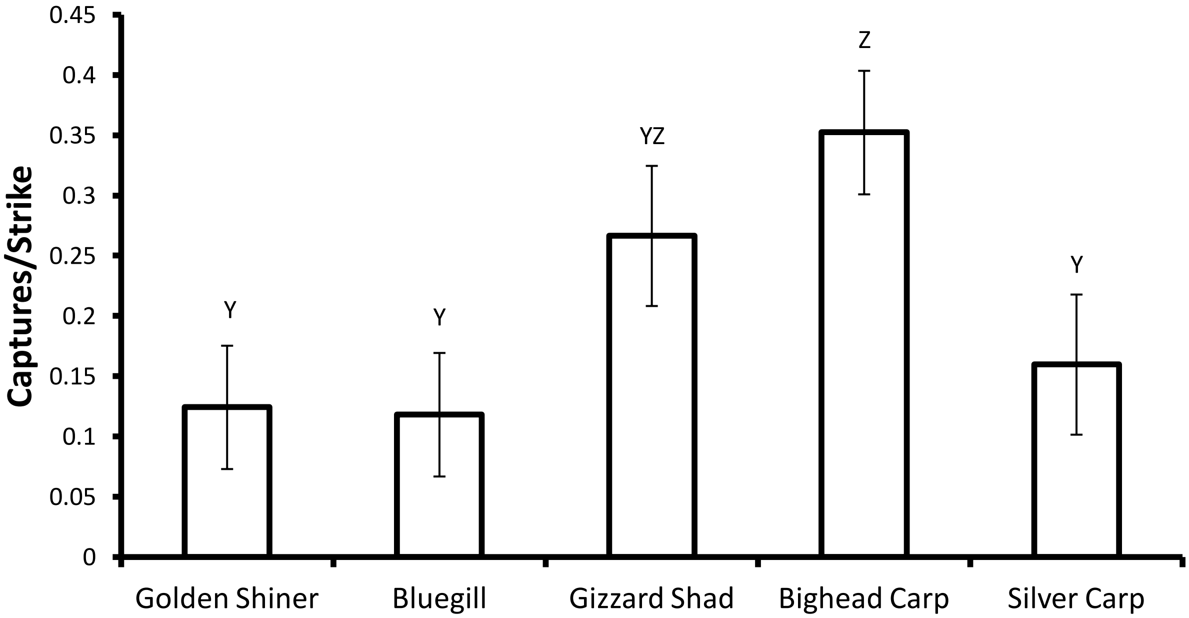

Figure 1.3. Mean number of jumps (± SE) with each prey species; golden shiner, bluegill, gizzard shad, bighead carp, and silver carp. Different letters represent statistically significant differences.

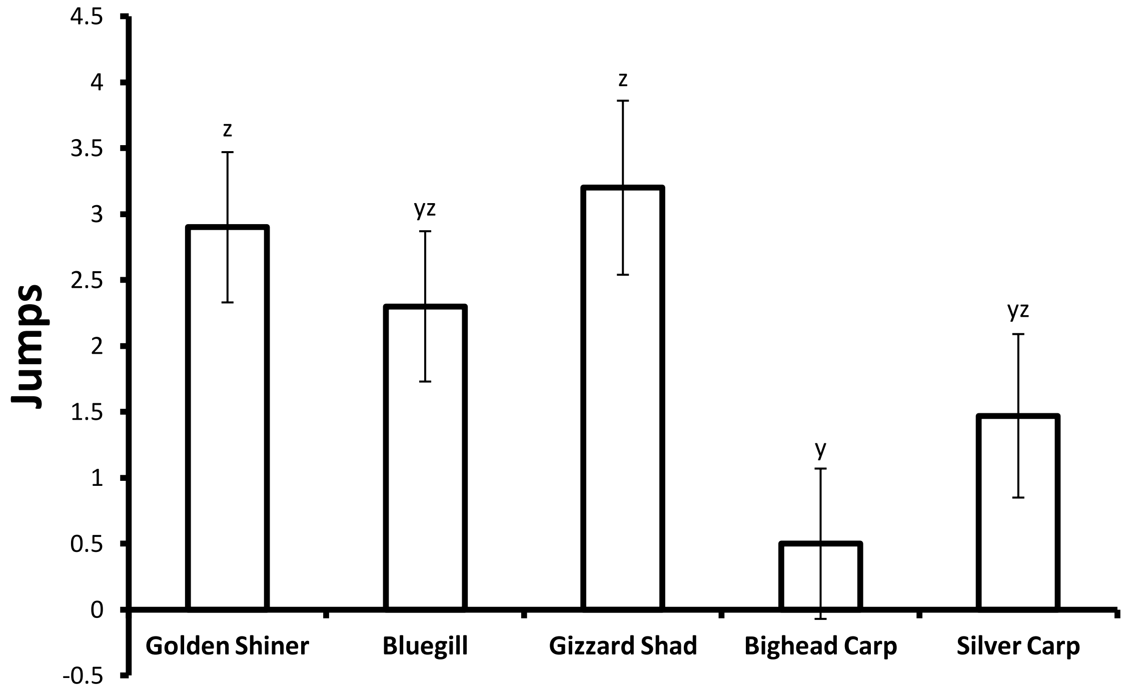

Figure 1.4. Mean school size (± SE) with each prey species; golden shiner, bluegill, gizzard shad, bighead carp, and silver carp. Different letters represent statistically significant differences.

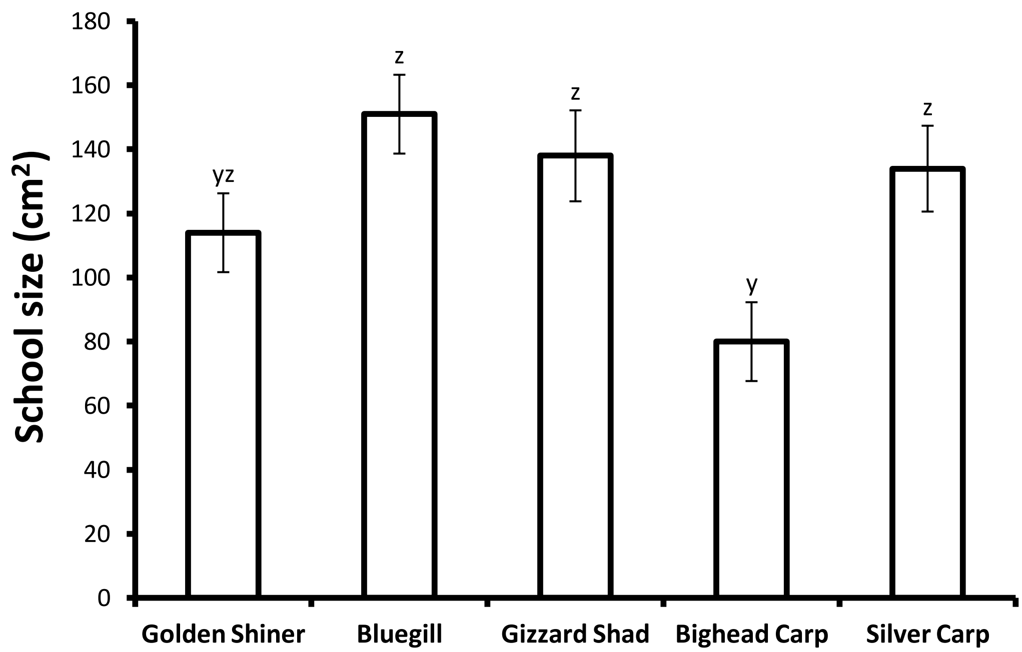

Figure 2.1. Mean values (± SE) of consumption (g/g/d) for day one and week one of each shape treatment and controls. Different letters denote statistically significant differences.

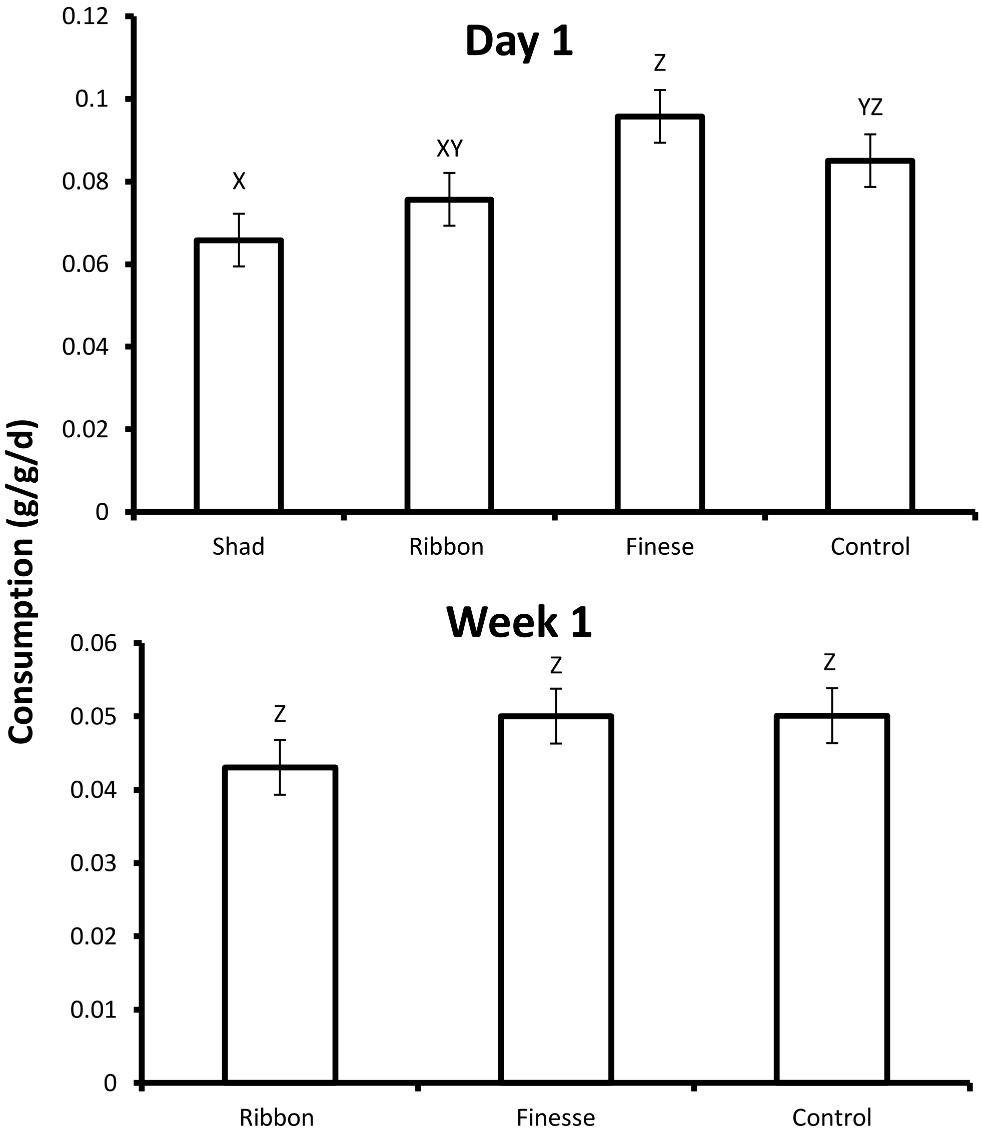

Figure 2.2. Mean values (± SE) of consumption (g/g/d) for day one and week one of each material treatment and controls. Different letters denote statistically significant differences. Biodegradable baits are Berkley Gulp! lures which are advertised to break down in the environment while the non-biodegradable baits are lures made of PVC.

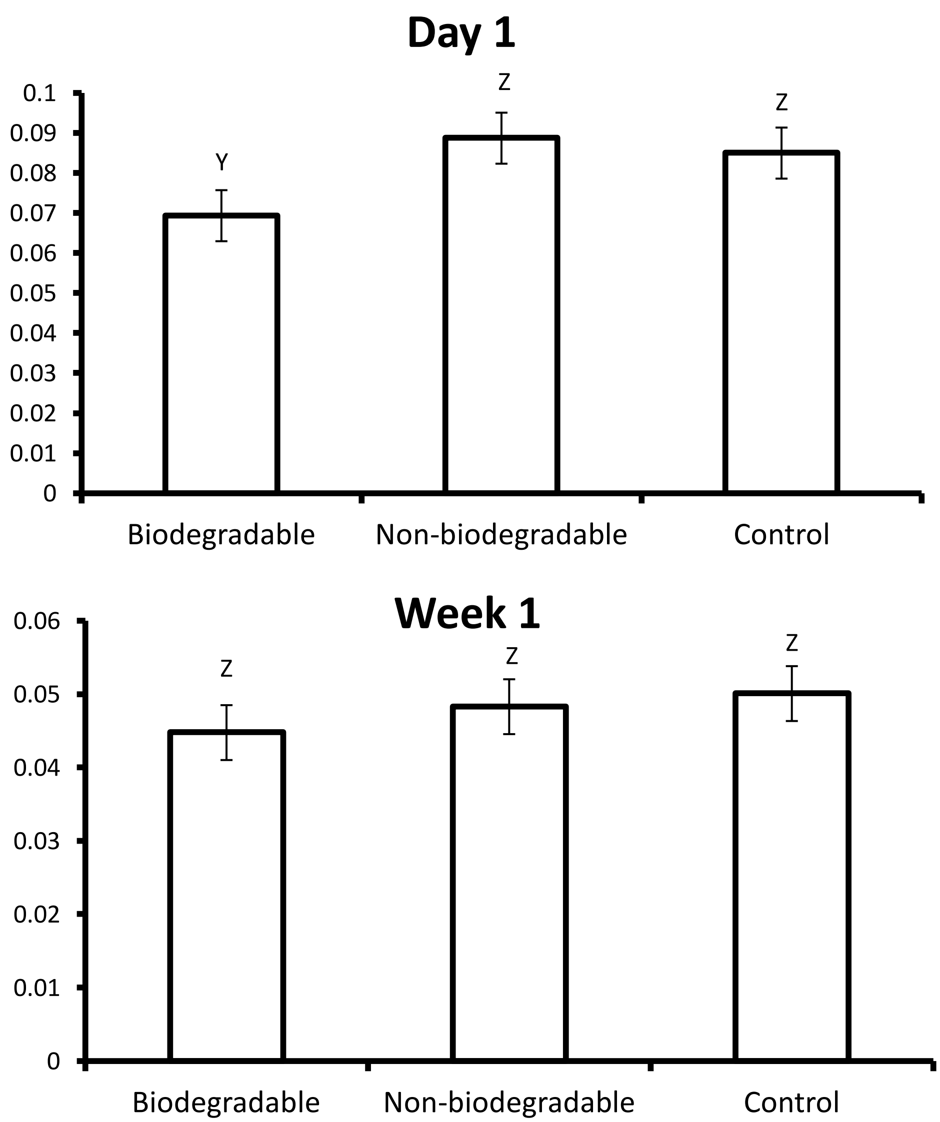

Figure 2.3. Mean days to expulsion (± SE) of three shapes (A) and material (B). Different letters indicate statistically significant differences.